LOCATING CABLE FAULTS

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1. INTRODUCTION.

1.1 Aerial line faults can usually be located by visual inspection of the line and only in certain instances, such as a trunk line fault, is there a need to make an electrical location test to determine the affected section of the line prior to the visual inspection.

1.2 Visual inspection is also an important part of locating faults in cables but as cables are underground and not readily accessible unless excavated, electrical testing is usually necessary beforehand to determine the site or locality of the fault condition.

1.3 This paper details location methods which are applied to cable faults together with a description and use of the more common types of testing instruments available for this type of work.

2. ORIGIN OF FAULT REPORTS.

2.1 A fault is any condition which interferes with the normal working of a service. These conditions can occur in:-

(i) Internal Plant e.g. exchange or substation equipment, and

(ii) External Plant e.g. aerial wires, cables and terminal units.

2.2 Faults may be reported by:-

(i) Technicians as the result of routine maintenance testing.

(ii) Subscribers who experience difficulty with their service.

(iii) Members of the public, other departments and public utilities, who have damaged (or discovered damage to) plant.

(iv) Linemen in the normal course of their duties.

The nature of the report will vary considerably depending on what the person has observed or experienced.

2.3 Details of the fault are recorded in the metropolitan areas at centralised testing centres from which the affected lines and equipment can be tested. In smaller areas, the information is relayed to the test desk technician at the exchange which controls the affected services. In both cases, testing is carried out in conjunction with fault linemen to determine:-

(i) the type of fault,

(ii) the extent of the fault,

(iii) whether internal or external plant is faulty, and

(iv) if external, whether fault is in aerial or cable construction.

2.4 If the result of the test indicates a cable fault, a cable jointer is despatched to locate (or assist in locating) the actual position of the fault and to restore the services. A "Depot Sequence Number" is allotted to the fault and used throughout the fault clearance work to identify this particular fault.

3. ELEMENTS OF FAULT LOCATION.

3.1 Fault location methods will vary depending on the type of fault, the number of services affected, the type of testing equipment available, etc. but the following elements should be adopted wherever practicable.

(i) Logical Deduction.

(ii) Electrical Testing.

(iii) Observation.

The application of these elements will eliminate any tendency to open cables and cable joints at random to locate the site of the fault.

3.2 Logical Deduction. The following details should be supplied by the Technician before proceeding on the fault:-

Isolated Faults	Cable Breakdowns
Subscribers Telephone Number	Cable number
Subscribers Name and Address	Cabinet/Pillars affected
Full details of cable feed	Full range of affected pairs
Type of fault.	Type of fault
	Any other information known which may assist in locating the fault.

These details should be entered in the Faultman's notebook and referred to when examining the cable record plans (copies of which are available in the Line Depot) to determine the most logical location of the fault and at which point an electrical test should be made.

3.3 Electrical Testing may be carried out by the:-

(i) "Test Desk" technician in conjunction with the cable jointer.

(ii) "Mobile Testing Officer" who is usually a Senior Technician.

(iii) Cable jointer working independently to isolate the faulty section.

3.4 Observation is an important part of fault work and is often the best guide to quickly determine the site of a fault. Some points to check in the affected locality are:-

(i) cable jointing works in progress or recently completed,

(ii) recent excavations in close proximity to the cable route,

(iii) jointing pits or terminal units that are damaged,

(iv) cable joints that are not properly sealed, and

(v) the lead sheath for warmth (a sign of moisture in the cable in Auto. and C.B. exchange areas if fuses have not been removed from the faulty pair).

3.5 Fig. 1 shows a typical fault procedure used for isolated faulty pairs only. Appropriate testing points for various stages of the job are shown together with the alternative procedures that may be adopted on the completion of each test. If details of the approximate location of the fault are available or a range of pairs is affected due to a cable breakdown, an appropriate section of the sequence shown in Fig. 1 can be selected and work commenced in that area.

3.6 While deduction, testing and observation are being applied to locate the fault, action should be taken, if practicable, to temporarily restore the affected services to normal working (see the paper "Repairing Faulty Cables").

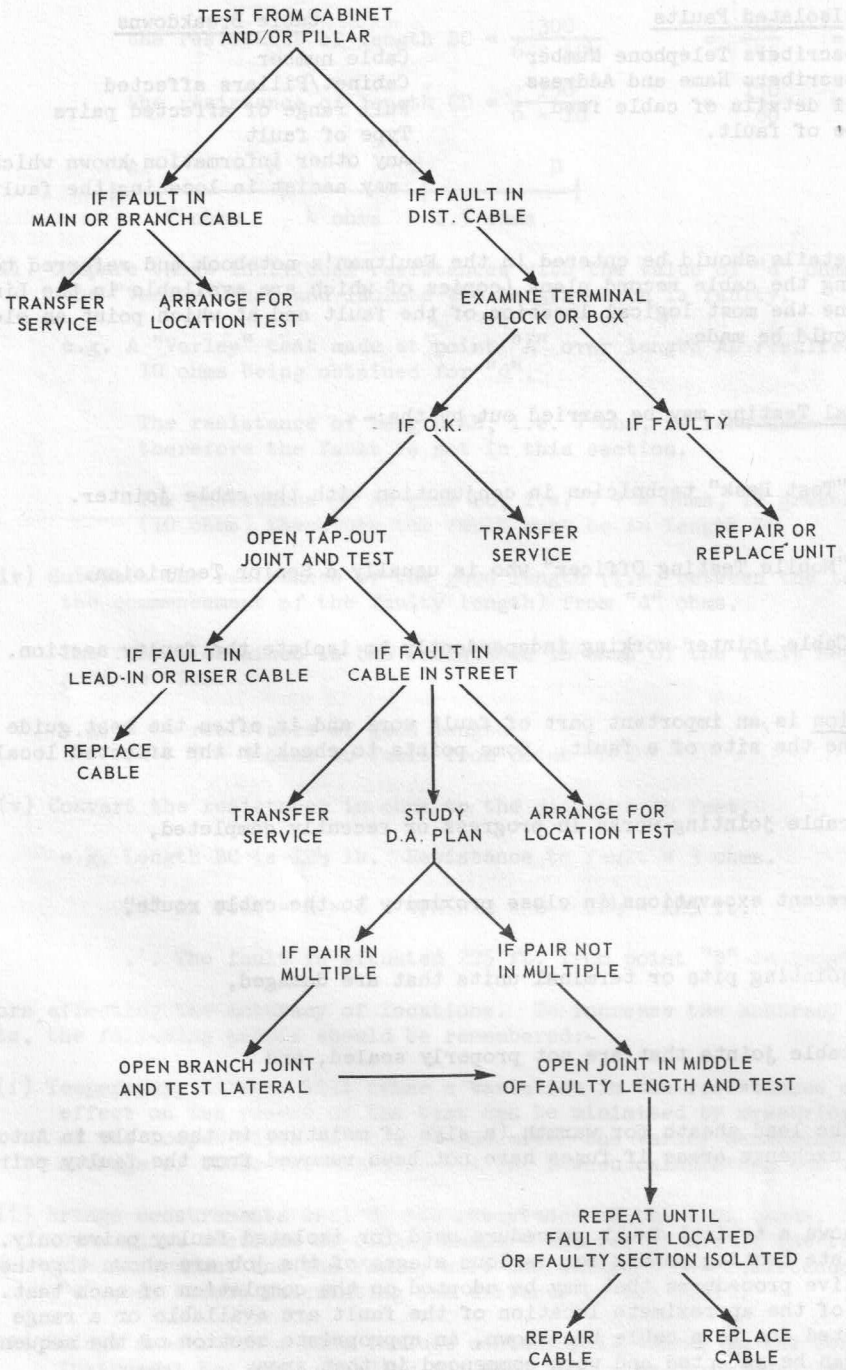

TEST FROM CABINET AND/OR PILLAR
IF FAULT IN MAIN OR BRANCH CABLE
IF FAULT IN DIST. CABLE
TRANSFER SERVICE
ARRANGE FOR LOCATION TEST
EXAMINE TERMINAL BLOCK OR BOX
IF O.K.
IF FAULTY
OPEN TAP-OUT JOINT AND TEST
TRANSFER SERVICE
REPAIR OR REPLACE UNIT
IF FAULT IN LEAD-IN OR RISER CABLE
IF FAULT IN CABLE IN STREET
REPLACE CABLE
TRANSFER SERVICE
STUDY D.A. PLAN
ARRANGE FOR LOCATION TEST
IF PAIR IN MULTIPLE
IF PAIR NOT IN MULTIPLE
OPEN BRANCH JOINT AND TEST LATERAL
OPEN JOINT IN MIDDLE OF FAULTY LENGTH AND TEST
REPEAT UNTIL FAULT SITE LOCATED OR FAULTY SECTION ISOLATED
REPAIR CABLE
REPLACE CABLE

FIG. 1. TYPICAL FAULT PROCEDURE FOR ISOLATED FAULTY PAIRS ONLY.

4. TESTING WITH LINES TEST SET NO.1.

4.1 The Lines Test Set No. 1. (Fig. 2) is a portable voltmeter reading 0-80 Volts. By means of a switch on the front panel, the voltmeter is converted to an ohm meter by bringing into circuit a 30 Volt dry cell in series with the voltmeter. The ohm meter scale is calibrated in megohms (1 megohm = 1,000,000 ohms) and decimals of megohms.

Two flexible insulated test leads are supplied which are connected to the set by banana plugs and sockets. The leads are fitted with probes and alligator clips. The 30 Volt battery in the test set may be checked by shorting the test leads with the switch on "Megohms" and referring to the scale. The needle should give a reading within the "Battery O.K." range.

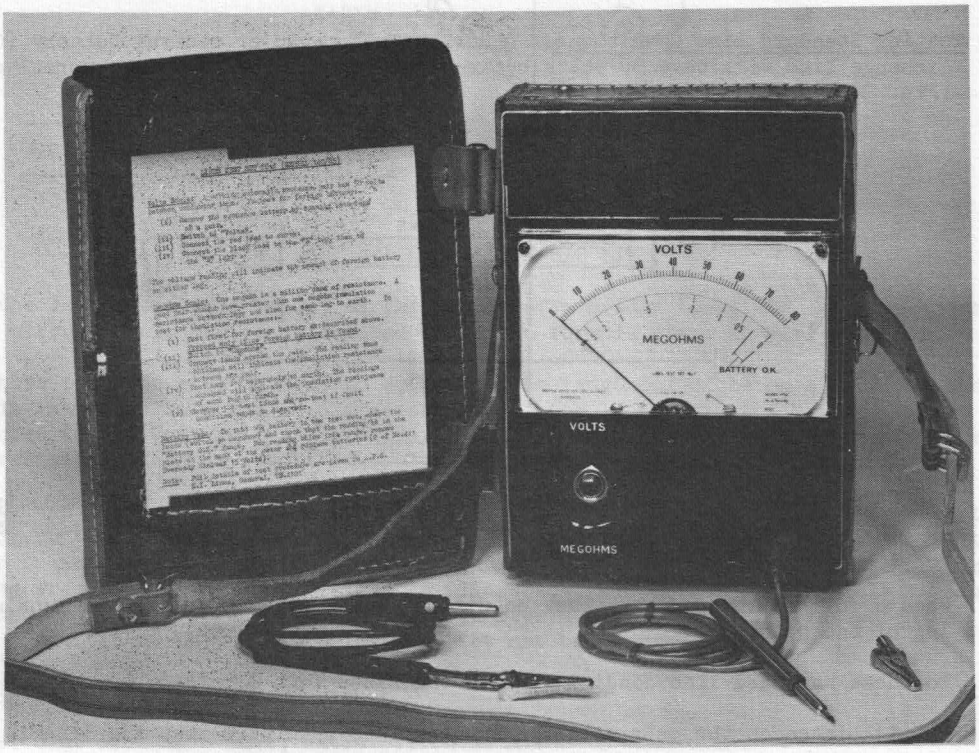


FIG. 2. LINES TEST SET NO. 1.

4.2 This set has been designed to enable the lineman to test telephone lines from terminal points such as cabinets, pillars, cable boxes etc.

The set will indicate the type of fault e.g. Low insulation resistance (L.I.R.), earth, open circuit, short circuit, foreign battery. It will show the general location of the fault i.e. between cabinet and pillar, country side of pillar etc.

The use of this set will reduce the number of tests the linemen will require from the exchange test desk and will also indicate by the reading, whether the Testing Technician will be able to give an accurate location of the fault.

The Lines Test Set has been designed to have characteristics similar to those of the exchange test desk meter, so that the readings of fault conditions on both meters will be comparable.

4.3 Precautions. Care must be taken to protect the meter from damage both in transit and while in use. Observe the following:-

(i) Store the set in a compartment separate from tools and material.

(ii) Place the leather strap around the neck to hold the meter in a safe and convenient position when working on a pole, etc.

(iii) To avoid damage to the meter from an excessive voltage, do not connect the set to an energised line (i.e. carrying battery) when the meter switch is in "Megohm" position.

(iv) As an additional precaution, always place the switch in "Volts" position when the meter is not in use.

4.4 Testing Standard Line Conditions. A working automatic or central battery (C.B.) exchange line will have 50 volts between the legs of the pair as a normal condition (Fig. 3).

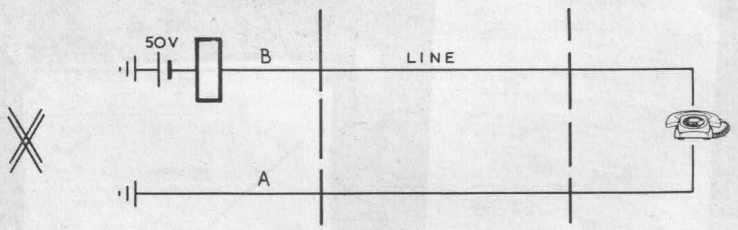


FIG. 3. SUBS LINE - NORMAL.

The "A" side of the pair is connected to the exchange earth and "B" side is connected to the negative terminal of the exchange battery, the positive terminal of the exchange battery being earthed.

When a call is in progress (busy condition) some value of voltage will exist on each leg of the pair.

To check standard line conditions with the Lines Test Set (Fig. 4):-

(i) Listen on the pair with the buttinski to make sure that the line is not in use.

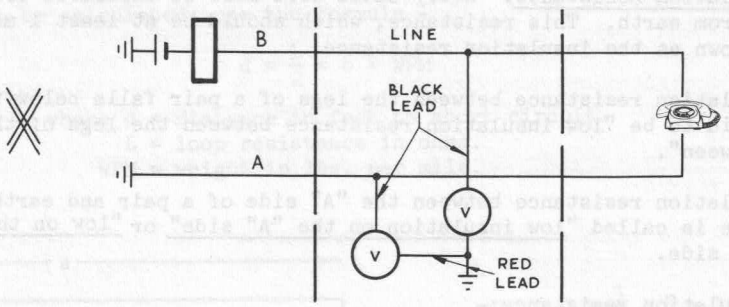
(ii) Switch to "Volts" position.

(iii) Connect the red lead (marked +ve) to earth, (sheath of lead covered cable, or insert the test probe into moist ground).

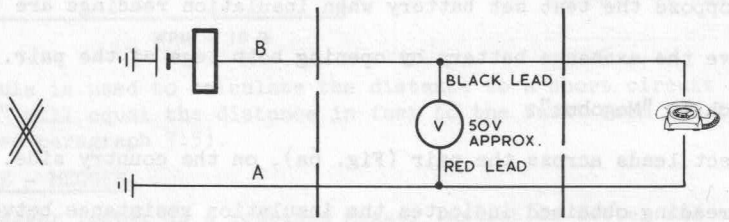
(iv) Tap the black lead (marked -ve) onto each leg of the pair (Fig. 4a). The meter should read approximately 50 volts when the "B" leg is tested. The "A" leg, being earthed will give a "zero" volts reading.

(v) Connect the red lead to the "A" side of the pair and the black lead to the "B" side. A reading of approximately 50 Volts should record on the meter. (Fig. 4b).

If testing at a point where the "A" and "B" sides are known, (iii) and (iv) above can be omitted.



(a) Identifying "A" and "B" sides.



(b) Testing for Exchange Battery.

FIG. 4. TESTING STANDARD LINE CONDITIONS.

4.5 Testing for Foreign Battery. (Fig. 5). Current leakage from one circuit to another, due to poor insulation or a contact, results in a foreign battery fault. To isolate the affected section, select a suitable test point and proceed as follows:-

(i) Remove the exchange battery by opening both legs of the pair e.g. at a pillar remove the jumper.

(ii) Switch to "Volts".

(iii) Connect the red lead to earth. (See para. 4.4 (iii)).

(iv) Connect the black lead to the "A" leg, then to the "B" leg, on the country side of the line.

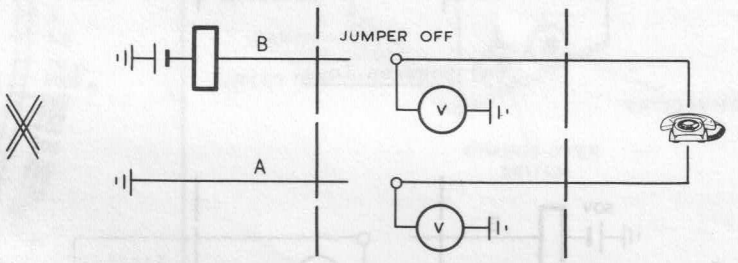


FIG. 5. TESTING FOR FOREIGN BATTERY.

(v) A voltage reading on either leg indicates the amount of foreign battery in the section under test (i.e. towards subscriber).

(vi) If the reading is "zero" for both legs of the pair there is no foreign battery present on this section; the fault is therefore towards the exchange.

(vii) Repeat (i) to (iv) at the next test point selected (for (v) this point will be closer to the subscriber and for (vi) closer to the exchange), until fault position located or affected section isolated.

4.6 Testing Insulation Resistance. Every cable wire must be insulated from all other wires and from earth. This resistance, which should be at least 1 megohm (1,000,000 ohms) is known as the insulation resistance.

If the insulation resistance between the legs of a pair falls below this figure, there is said to be "low insulation resistance between the legs of the pair" or, "L.I.R. between".

If the insulation resistance between the "A" side of a pair and earth falls below one megohm, this is called "low insulation on the "A" side" or "low on the "A"", similarly for the "B" side.

To test insulation resistance:-

(i) Test first for foreign battery (para. 4.5), as the foreign potential may aid or oppose the test set battery when insulation readings are being taken.

(ii) Remove the exchange battery by opening both legs of the pair.

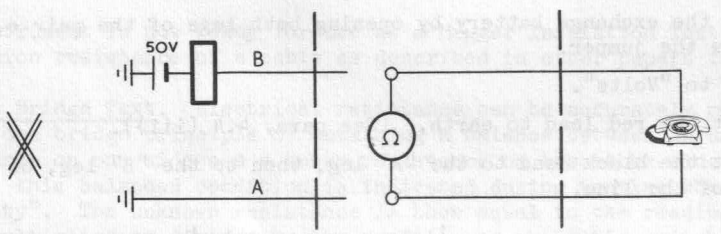
(iii) Switch to "Megohms".

(iv) Connect leads across the pair (Fig. 6a), on the country side.

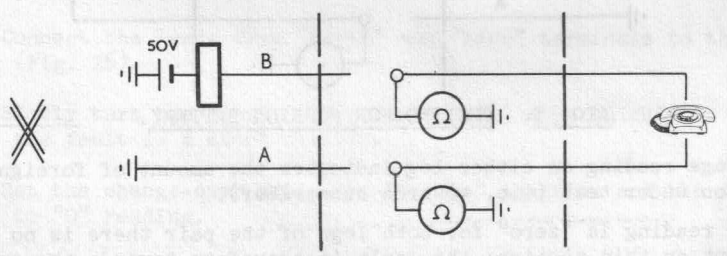
(v) The reading obtained indicates the insulation resistance between the pair.

(vi) Test each leg separately to earth to determine the insulation resistance to earth of each side. (Fig. 6b).

(vii) Reverse the test leads and re-test if fault condition tends to disappear (See para. 4.12).



(a) Between Legs.



(b) From A and B Legs to Earth.

FIG. 6. TESTING INSULATION RESISTANCE.

What insulation resistance readings mean:-

(a) Less than 0.05 megohms (i.e. 50,000 ohms) the Testing Technician will be able to give a location.

(b) Between 0.05 and 0.5 megohms (50,000 ohms and 500,000 ohms) it is unlikely that the Testing Technician will be able to give an accurate location.

(c) Between 0.5 and 1 megohm (500,000 ohms and 1,000,000 ohms) the line is faulty but will give reasonable service.

(d) Above 1 megohm the line is good, but where possible, better than 2 megohms is desirable.

4.7 Earth Test. This test is similar to the test for insulation resistance as shown in Fig. 6b. If the meter shows almost a full scale deflection the leg under test is earthed. If no deflection is shown the leg is O.K. in that section.

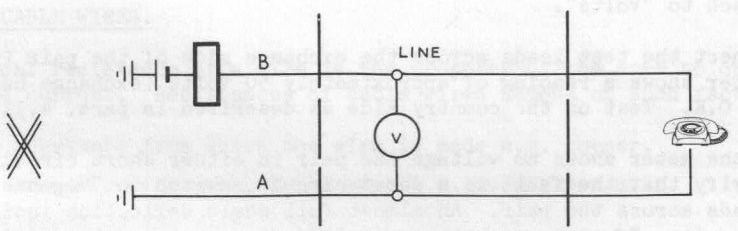
4.8 Open Circuit Test "Exchange Side".

(i) Switch to "Volts".

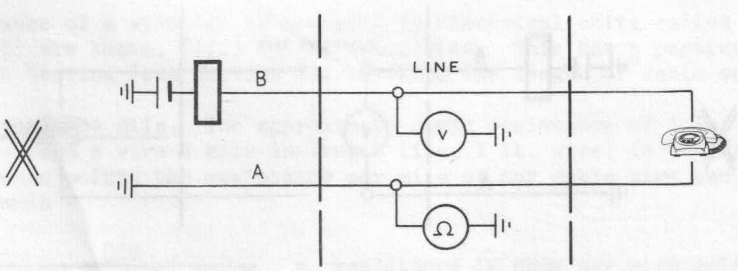
(ii) Connect the leads across the pair (Fig. 7a); a reading of approximately 50 volts will prove the continuity of both legs back to the exchange. In this case, test the country side as described in para. 4.9.

(iii) If the open circuit proves to be back to the exchange, establish which leg is open by testing each leg to earth (Fig. 7b). The "B" side, should show a reading of approximately 50 volts. If the meter reads zero the leg is open.

(iv) To test the "A" leg switch to "Megohms". As the "A" leg is earthed at the exchange the meter should show almost a full scale deflection if the leg is continuous. If it is open there will be no deflection on the meter.



(a) Across Pair.



(b) Testing Each Leg.

FIG. 7. TESTING FOR OPEN CIRCUIT. (EXCHANGE SIDE).

4.9 Open Circuit Test (Country Side).

(i) Remove jumpers of the pair to be tested (at pillar etc.).

(ii) Switch to "Volts".

(iii) Connect the leads across the pair (country side). Wait 5 seconds for the capacitor (condenser) in the subscriber's telephone to discharge through the meter.

(iv) Switch to "Megohms" (Fig. 8) and watch for a momentary deflection equivalent to about .05 megohms caused by the charging of the capacitor by the 30 volt battery in the test set.

(v) To confirm the test, switch back to "Volts" and wait 5 seconds, then switch to "Megohms" and note the deflection. If there is no deflection the pair is open.

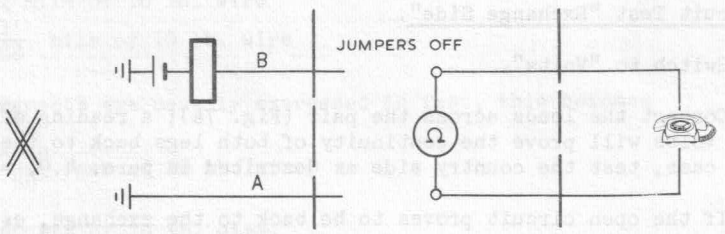


FIG. 8. TESTING FOR OPEN CIRCUIT (COUNTRY SIDE).

4.10 Short circuit test (Exchange side).

(i) Remove jumpers of the pair to be tested (at pillar etc.).

(ii) Switch to "Volts".

(iii) Connect the test leads across the exchange side of the pair (Fig. 9). If the meter shows a reading of approximately 50 Volts (exchange battery) the pair is O.K. Test on the country side as described in para. 4.11.

(iv) If the meter shows no voltage the pair is either short circuited or open. To verify that the fault is a short circuit, switch to "Megohms" and connect the leads across the pair. An almost full scale deflection indicates a short circuit. If exchange battery is indicated on the meter don't use ohmmeter!

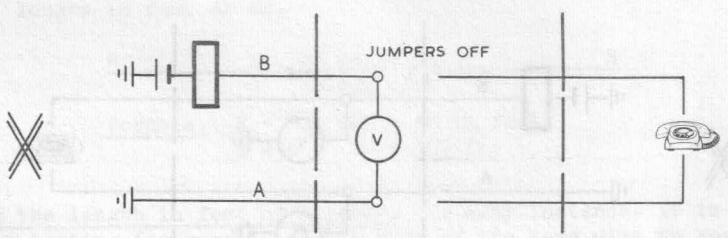


FIG. 9. TESTING FOR SHORT CIRCUIT (EXCHANGE SIDE).

4.11 Short Circuit Test (Country Side).

(i) Remove jumpers of the pair to be tested (at pillar etc.).

(ii) Switch to "Volts".

(iii) Connect the leads across the country side of the pair. Wait 5 seconds for the condenser in the subscriber's telephone to discharge through the meter.

(iv) Switch to "Megohms". (Fig. 10). If the meter gives almost a full scale deflection and remains at that reading, the pair is short circuited. If a momentary deflection of about .05 megohms is seen, the line is O.K.

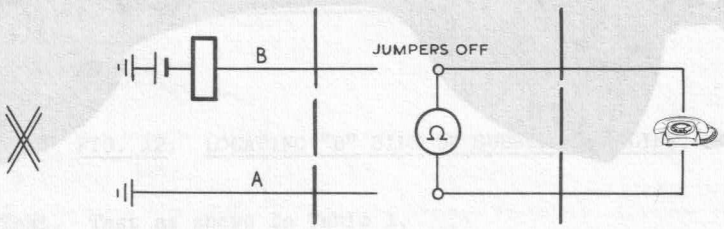


FIG. 10. TESTING FOR SHORT CIRCUIT (COUNTRY SIDE).

4.12 Testing at Encapsulated Joints. This instrument has a wide application in fault testing, but is particularly useful when localising faults in plastic cables. It should be noted however, that plastic cable faults usually polarise quickly and the fault condition tends to disappear within a minute or two. By reversing the current through the fault (i.e. by changing the test leads) the original fault condition will re-appear.

Faults that occur in encapsulated epoxy resin joints can usually be seen as a milky or candied mass through the clear plastic mould. When the joint is covered with a semi-transparent submarine type mould it may be necessary to peel off the mould to see the fault zone. Where a hole exists in the moulded resin which may have allowed the entry of moisture to the wires, existence of a fault condition can be verified by inserting the probe of the black lead (meter switch in "Volts" position) into the hole and connecting the red lead to earth. The voltage reading will indicate that the joint is faulty.

The same technique can be applied to epoxy joints covered with lead or aluminium moulds by measuring the voltage of the mould to earth. To test non-working pairs that may be low to the metallic mould, run a lead to the nearest break point (pillar etc.) and use the test set to check the insulation resistance between each wire and the mould. It should be noted that, with metallic moulds on epoxy encapsulated joints, the leakage current path to earth will disappear as soon as the joint is lifted out of the water in a pit.

5. TESTING WITH BUTTINSKI.

5.1 When other testing instruments, such as the Lines Test Set, are not readily available, a considerable amount of effective time can be lost on fault work by Lineman waiting at test points for tests to be made by Exchange Technicians or other Testing Officers. This is often the case during wet periods when the fault incidence is usually high.

In automatic exchange areas, the Buttinski can be used by a lineman to localise the faulty section of the affected line.

5.2 The buttinski is a portable assembly of receiver, transmitter, dial etc. fitted with a two conductor cord terminated on suitable alligator clips for use on telephone lines in automatic and central battery exchange areas. The latest type of buttinski, the Handset No. 4, is shown in Fig. 11. Listening, dialling and speaking facilities are obtained by operating the thumb switch. Earlier issues of the buttinski are fitted with a spring loaded push-button switch which is operated to obtain the desired facility.

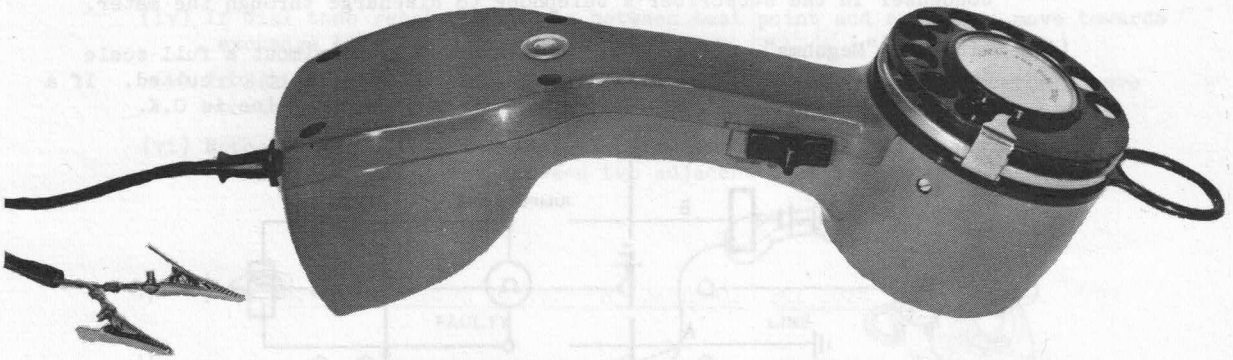


FIG. 11. A TYPICAL BUTTINSKI - HANDSET NO. 4.

5.4 Good Public Relations. When using a buttinski on subscribers lines always remember that you must be:-

(i) Confidential. Do not reveal to other persons any details of a conversation that you may have overheard.

(ii) Courteous. If the subscriber answers his telephone, inform him that you are a P.M.G. Lineman working on the line and to ignore any future "tinkles" of the bells.

(iii) Co-operative. If subscriber desires to use the line or is expecting to receive a call, release the line.

(iv) Considerate. When the subscriber will be disturbed by repeated use of the line, open circuit the line if this is agreeable to the subscriber. Notify subscriber when line restored.

5.3 Use of Buttinski. To make a call over an automatic line to official numbers such as the Line Depot, Exchange, Cable Records, etc:-

(i) Select a public telephone line, if possible, and connect the buttinski leads.

(ii) Listen to ensure that line is not in use. If conversation is heard, select another line or wait until subscriber has finished.

(iii) Operate the switch to loop the line and obtain dial tone.

(iv) Dial the desired number.

5.5 Locating the Battery ("B") Side of a Subscribers Line. When testing faulty lines with the buttinski it is often necessary to use the "B" side of a normal subscribers line.

To locate the "B" side (Fig. 12):-

(i) Listen with the buttinski to ensure that the line is not in use.

(ii) Disconnect buttinski from the line then connect one lead to earth.

(iii) With switch operated, connect the other lead to each side of the pair in turn.

(iv) Dial tone will be received when the "B" side is contacted.

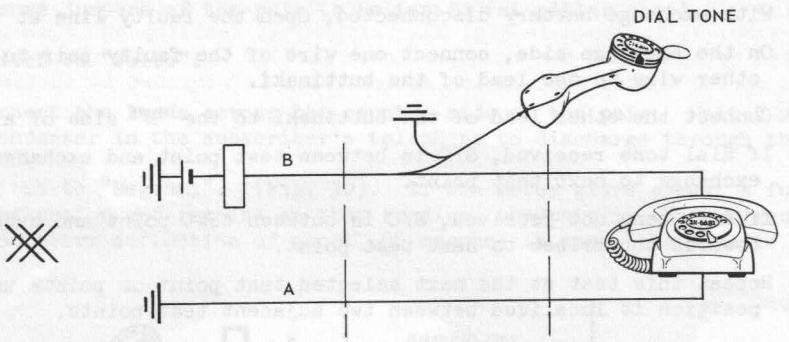


FIG. 12. LOCATING "B" SIDE OF SUBSCRIBERS LINE.

5.6 Open Circuit Test. Test as shown in Table 1.

Purpose of Test	Testing Procedure	Result of Test	
		Dial Tone Received	No Dial Tone
To prove which section of the faulty line is O/C.	With the exchange battery connected to the faulty line i.e. fuses or links not removed, connect buttinski to the faulty pair at test point.	O.K. between test point and exchange - move towards subscriber to next test point.	O/C between test point and exchange-move towards exchange to next test point.
	Repeat as above at next selected test point (or points) until fault position localised between two adjacent test points.	As above.	As above.
To prove whether one or both sides of the line are O/C in the faulty section.	At a test point where O/C is located towards exchange, connect one lead from buttinski to "B" side of a subscribers line, other lead to each side of faulty pair in turn.	"A" side O.K.	"A" side O/C.
	Repeat as above, but connect one lead from buttinski to earth, other lead to each wire in turn.	"B" side O.K.	"B" side O/C.

TABLE 1. TESTING PROCEDURE FOR OPEN CIRCUIT FAULT.

5.7 Short Circuit Test (Fig. 13). To prove which section of the line is S/C, test as follows:-

(i) With exchange battery disconnected, open the faulty line at the test point.

(ii) On the exchange side, connect one wire of the faulty pair to earth and the other wire to one lead of the buttinski.

(iii) Connect the other lead of the buttinski to the "B" side of a subscribers line.

(iv) If dial tone received, S/C is between test point and exchange; move towards exchange to next test point.

(v) If dial tone not received, S/C is between test point and subscriber; move towards subscriber to next test point.

(vi) Repeat this test at the next selected test point or points until fault position is localised between two adjacent test points.

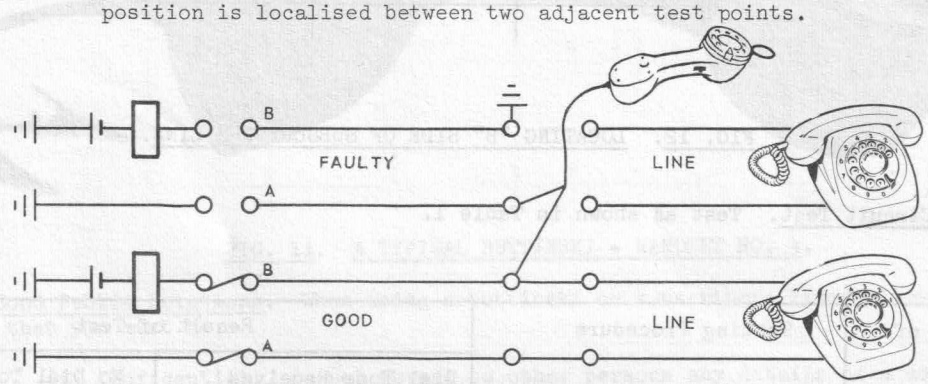


FIG. 13. TESTING CONNECTIONS FOR S/C FAULT.

5.8 Earth Test (Fig. 14). To prove which section of the line is earthed, test as follows:-

(i) With exchange battery disconnected, open the faulty line at the test point.

(ii) Connect one lead of the buttinski to the "B" side of a subscribers line.

(iii) On the exchange side, connect the other lead of the buttinski to each wire of the faulty pair in turn.

(iv) If dial tone received, the wire connected to the buttinski is earthed between the test point and the exchange; move towards the exchange to next test point.

(v) If dial tone not received, the earth fault is between the test point and the subscriber; move towards the subscriber to next test point.

(vi) Repeat this test at the next selected test point or points until the fault position is localised between two adjacent test points.

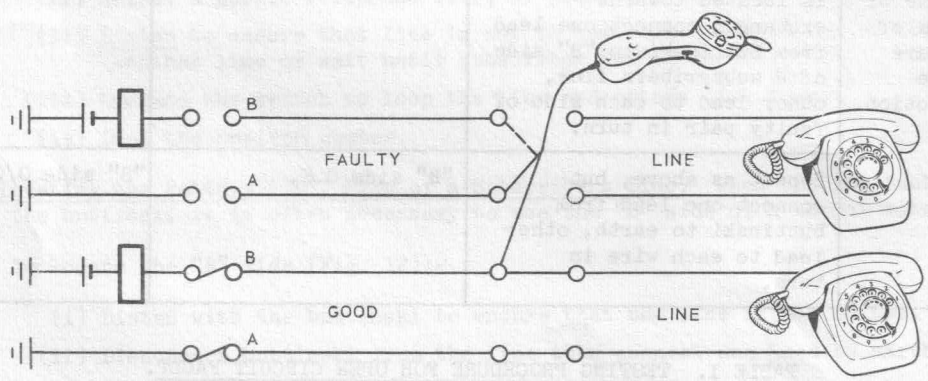


FIG. 14. TESTING CONNECTIONS FOR EARTH FAULT.

5.9 "Leakage to Earth" Test. When testing for an earth fault (as described in paragraph 5.8), dial tone may not be received but the line may be noisy (e.g. a frying sound). This is an indication that leakage is occurring between the line and earth due to low insulation resistance. Testing can be continued as described for an earth fault but remember that a frying sound, not dial tone, will be received.

5.10 Cross or Contact Test. Test as shown in Table 2.

Purpose of Test	Testing Procedure	Result of Test
To prove that the two lines are crossed.	With the exchange battery connected to the two lines affected, connect buttinski across one line.	Dial tone should be received.
	Leave buttinski connected to one line and short circuit the other line.	If interference is caused (i.e. a click is heard) then the lines are crossed - remain at test point.
To prove which section of the lines are crossed.	Open circuit one of the lines and connect the buttinski to the exchange side of this line. Short circuit the other line.	If click is heard, fault is between test point and exchange - move towards exchange to next test point. If click is not heard, fault is between test point and subscriber - move towards subscriber to next test point.
	Repeat previous test at next selected test point or points until fault position localised.	As above.

TABLE 2. TESTING PROCEDURE FOR CROSS OR CONTACT FAULT.

6. RESISTANCES OF CABLE WIRES.

6.1 The electrical resistance of a wire is the property of the wire to oppose the flow of an electric current. Resistances of cable wires depend on such factors as:-

(i) The substance from which the wire is made e.g. copper.

(ii) The cross-section area of the wire i.e. weight per mile.

(iii) The length of the wire.

(iv) The temperature of the wire. (This effect is relatively small and is not taken into account in most practical situations).

The resistance of a wire can be measured in electrical units called "ohms" and, when (i) and (ii) are known, (iii) can be calculated. This has a particular application in location testing (see Section 7), checking the length of cable on a drum, etc.

6.2 Resistance per wire mile. The approximate ohmic resistance of 1 lb. of copper when extruded to form a wire 1 mile in length (i.e. 1 lb. wire) is 880 ohms. Using this as a reference point, the resistance per mile of any cable wire can be found by use of the formula -

$$\frac{880}{\text{Weight per mile (WPM)}} = \text{resistance in ohms per wire mile.}$$

Example. 10 lb. wire = $\frac{880}{10}$ = 88 ohms per wire mile.

The resistances per mile shown in Table 3 are slightly greater than the exact resistances, but, when used to calculate the length of a cable, the slightly greater resistances compensates for the "stranding" of the cable wires.

Weight (in lbs.) per mile (WPM)	4	6½	10	12½	20	40
Resistance in ohms per wire mile	220	135.4	88	70.4	44	22

TABLE 3. RESISTANCES OF COPPER CABLE WIRES.

6.3 Length in feet per ohm of resistance. With the resistance per wire mile known, the length of wire which is equal to 1 ohm of resistance can be found by deduction as follows -

If 88 ohms = 1 mile of 10 lb. wire

then 1 ohm = $\frac{1}{88}$ mile of 10 lb. wire

As wire measurements are usually expressed in feet, this becomes

1 ohm = $\frac{5280}{88}$ feet of 10 lb. wire

or 1 ohm = 60 ft. of 10 lb. wire.

An easier method to do this is to use the formula -

6 × WPM = No. of feet per ohm
e.g. 10 lb. wire = 6 × 10 = 60 ft. per ohm.

This formula can be adapted to find the length of a single wire (see paragraph 6.4), or the length of a cable (see paragraph 6.5), when the resistance has been measured.

6.4 Calculating the length in feet of a single wire. The resistance in ohms of a single wire is converted to determine the length of the wire by the application of the following formula:-

R (resistance in ohms) × 6 × WPM = length in feet of single wire.

Example. The resistance (R) of a length of 10 lb. wire (AB) is 5 ohms. Calculate the length in feet of AB.

A ——— 10 lb. wire ——— B
R = 5 ohms.

Formula. R × 6 × WPM = AB in feet.
5 × 6 × 10 = 300 ft.

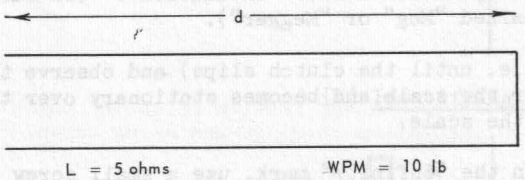
6.5 Calculating the length in feet of a cable. In many instances it is not practicable to connect the testing instrument to both ends of the same wire to measure its single wire resistance. The alternative method is to make the resistance measurement over a pair of wires which are connected to the instrument at one end and short circuited at the other end. The value of resistance obtained is the total resistance of the wire from the instrument to the short circuit and back to the instrument. This is called the "loop resistance". It must be remembered that if the formula given in paragraph 6.4 is used, the total length of wire in the circuit will be found.

If the length of the cable (i.e. the distance from the instrument to the short circuit) is to be calculated, use the formula -

$$d = \frac{L}{2} \times 6 \times WPM$$

where d = distance in feet to short circuit.
L = loop resistance in ohms.
WPM = weight in lbs. per mile.

Example.



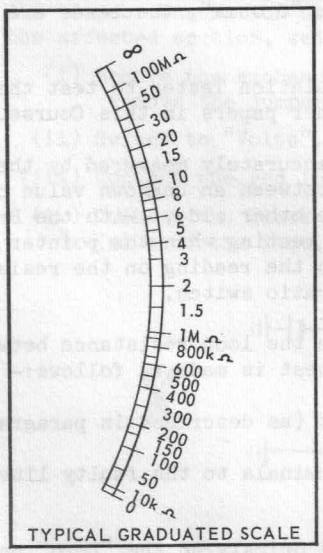
$$d = \frac{5}{2} \times 6 \times 10 = 150 \text{ ft.}$$

Length of cable = 150 feet.

The same formula is used to calculate the distance to a short circuit in a cable. In this case, "d" will equal the distance in feet to the fault from the testing instrument (see paragraph 7.5).

7. TESTING WITH BRIDGE - MEGGER.

7.1 The Bridge - Megger Tester is a combined Megger Insulation Tester and a complete Wheatstone Bridge. Several models of these instruments are available but the Series 2 (Fig. 15) is normally used in this Department to make insulation resistance and fault location tests.



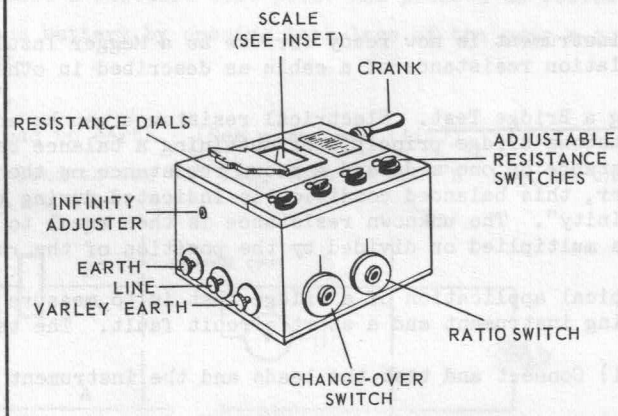


FIG. 15. A SERIES 2 BRIDGE - MEGGER.

7.2 This instrument comprises a hand driven generator to produce the testing voltage which is maintained at a constant pressure by a centrifugally controlled clutch incorporated between the turning handle and the armature shaft. The clutch will slip when the speed of the generator exceeds a predetermined value. The generator has two windings which are connected in series to deliver the rated voltage (i.e. 250V or 500V) for insulation resistance tests, or in parallel to deliver a lower voltage for bridge tests, by the operation of the change-over switch. When used as an insulation resistance tester, a moving coils ohmmeter measures directly the value of the insulation resistance which is shown on a scale calibrated in ohms and megohms.

7.3 The ohmmeter serves also as the galvanometer when the change-over switch is operated for the bridge tests. A direct reading adjustable resistance completes the bridge, the total value in circuit being shown on four dials as a row of figures. The adjustable resistances are variable from 1 to 9,999 ohms in 1 ohm steps. By use of the ratio switch the permissable range of measurement is from 1 ohm to 999,900 ohms.

7.4 Preparing Bridge - Megger for use. To avoid the possibility of false or misleading readings always:-

(i) Set the change-over switch to the position marked "Insulation". (On earlier models, this position may be marked "Meg" or "Megger").

(ii) Turn the crank at full speed (i.e. until the clutch slips) and observe that the pointer moves promptly over the scale and becomes stationary over the "Infinity" mark at the top of the scale.

(iii) If the pointer is not exactly on the "Infinity" mark, use a small screw driver to alter the setting of the infinity adjuster.

(iv) Connect suitable leads to the "Line" and "Earth" terminals.

(v) Ensure that the outer ends of the leads are not in contact with anything or each other and turn the crank at full speed.

(vi) If the pointer does not coincide with "Infinity", the leads are faulty i.e. leakage between the "Line" and "Earth" sides.

(vii) Short circuit the leads and turn the crank slowly. If the pointer does not move rapidly to the bottom of the scale i.e. "0 ohms", the leads are open circuit.

The instrument is now ready for use as a Megger Insulation Tester to test the insulation resistance of a cable as described in other papers in this Course.

7.5 Making a Bridge Test. Electrical resistance can be accurately measured by the Wheatstone bridge principle of obtaining a balance between an unknown value of resistance on one side and a known resistance on the other side. With the Bridge - Megger, this balanced condition is indicated during testing when the pointer reads "Infinity". The unknown resistance is then equal to the reading on the resistance dials multiplied or divided by the position of the ratio switch.

A typical application of a bridge test is to measure the loop resistance between the testing instrument and a short circuit fault. The test is made as follows:-

(i) Connect and test the leads and the instrument (as described in paragraph 7.4).

(ii) Connect the leads from "Earth" and "Line" terminals to the faulty line (Fig. 16).

(iii) Slowly turn the crank. The pointer will move quickly to the "Zero" mark if the fault is a short circuit.

(iv) Set the change-over switch to "Bridge" position and the four resistance dials to "0" reading.

(v) Set the ratio switch to "X1" position.

(vi) Turn the crank slowly while raising the resistance dial readings step-by-step (commencing with the left hand dial) until the pointer rests on the "Infinity" mark.

(vii) Adjustment of the ratio switch (see paragraph 7.6) may be desirable to obtain an accurate balance.

(viii) Increase the handle speed until the clutch slips to obtain the maximum sensitivity, and adjust the resistance dial readings as necessary to obtain a proper balance under these conditions.

(ix) Calculate the value of the loop resistance (L) from the reading of the dials in thousand, hundreds, tens and units (i.e. from the left hand side), multiplied or divided by the final setting of the ratio switch.

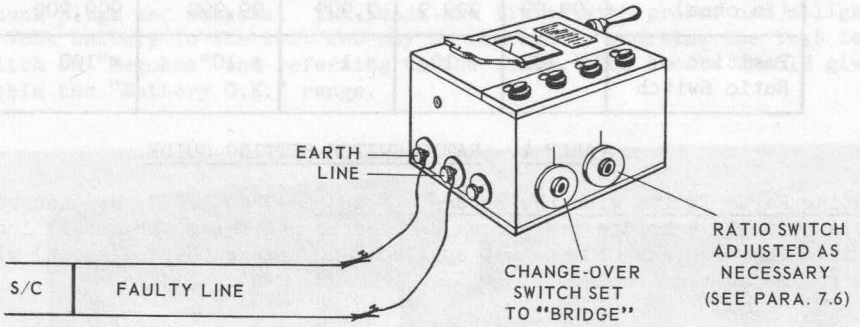


FIG. 16. BRIDGE TEST ON S/C LINE.

With the loop resistance known, as the result of a bridge test, the distance to the short circuit fault can be calculated using the formula given in paragraph 6.5.

The above test can also be used to determine the length of cable on a drum. A short circuit is placed on a cable pair at one end of the length and the bridge-megger connected to the same pair at the other end. A bridge test is made to measure the loop resistance and the length of cable calculated as described in paragraph 6.5.

7.6 Ratio switch settings. Maximum accuracy will be obtained from a bridge test when the reading on the resistance dials is as high as possible. Therefore, the ratio switch should be set as far as possible towards the ÷ 100 position to endeavour to obtain a reading from all of the four dials. To illustrate this point, the probable results obtained from three bridge tests, conducted over a pair of 20 lb. wires which are short circuited at an unknown point, are set out below.

Test 1.

Actual dial reading = 0042, Ratio Switch at X1. L = 42 ohms.
Using the formula

$$d = \frac{L}{2} \times 6 \times WPM$$

$$= \frac{42}{2} \times 6 \times 20 = \underline{2520 \text{ feet}} \text{ to the short circuit.}$$

Test 2.

Actual dial reading = 0421, Ratio switch at ÷ 10. L = 42.1 ohms.

$$d = \frac{42.1}{2} \times 6 \times 20 = \underline{2526 \text{ feet}} \text{ to the short circuit.}$$

Test 3.

Actual dial reading = 4215, Ratio switch at ÷ 100. L = 42.15 ohms.

$$d = \frac{42.15}{2} \times 6 \times 20 = \underline{2529 \text{ feet}} \text{ to the short circuit.}$$

Table 4 can be used as a guide for the ideal setting of the ratio switch. To gain maximum accuracy, this table should be consulted after the value of "L" has been determined, but before calculating "d". If necessary, adjust the ratio switch to the ideal setting and repeat the bridge test.

Value of "L" (in ohms)	1 to 99.99	100 to 999.9	1000 to 9,999	10,000 to 99,990	100,000 to 999,900
Position of Ratio Switch	÷ 100	÷ 10	× 1	× 10	× 100

TABLE 4. RATIO SWITCH SETTING GUIDE.

7.7 Locating Earth Faults with the Bridge - Megger. When L.I.R. has caused a section of cable to fail, a bridge-megger can be used to determine the actual location of the fault. The accuracy of the test applied (known as a "Varley" test) will depend on the following requirements:-

(i) A bridge-megger correctly adjusted and used as previously described.

(ii) A "good" wire over the section of cable to be tested. The wire may be:-

(a) in the cable; selected with the aid of an Insulation Tester,

or

(b) if all wires are faulty, provided by running out a length of insulated wire over the faulty cable section,

or

(c) a wire in another cable to which access can be gained at each end of the faulty cable section.

The "good" wire need not be of the same weight as the faulty wires.

(iii) A faulty wire with a low value of insulation resistance to earth. This should be below 50,000 ohms (0.05 megohms) to be able to obtain a reliable location.

7.8 Making a "Varley" test (Fig. 17).

(i) Connect the faulty wire to the good wire at distant end of faulty cable section.

(ii) Connect the good wire to the "Line" terminal of the bridge-megger and the faulty wire to the "Earth" terminal.

(iii) Set change-over switch to "Bridge" position and measure the loop resistance (as described in paragraph 7.5) and note the value obtained ("L") in ohms. "L" should equal 1 ohm or more to be able to continue with the test.

(iv) Connect the "Varley Earth" terminal to a good earth and set the change-over switch to "Varley" position.

(v) Obtain a balance (with the ratio switch in ÷ 100 position if possible) by varying the adjustable resistance dials and ratio switch as in a bridge test.

(vi) When a balance is obtained, note the actual numerical reading of the dials (which will be called "R") and also the setting of the ratio switch. Do not calculate the value of resistance as in a normal bridge test.

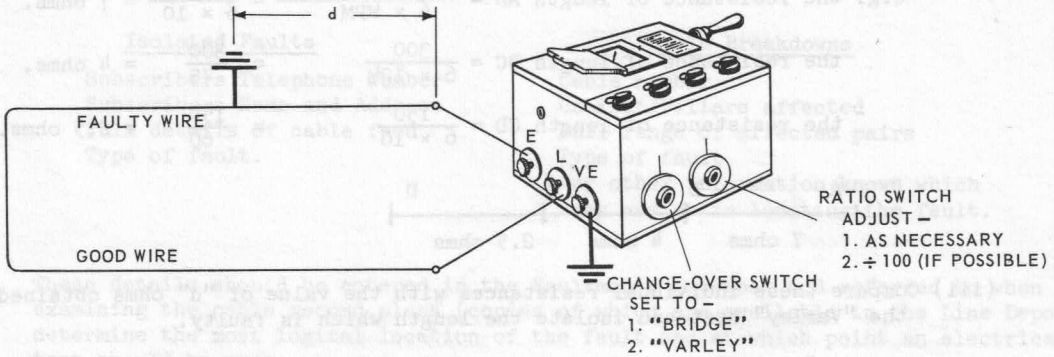


FIG. 17. "VARLEY" TEST CONNECTIONS.

(vii) The distance "d" in ohms between the fault and the instrument can then be calculated from the following:-

"d" ohms = $\frac{L - R}{2}$ if the ratio switch is at X_1 position

= $\frac{10L-R}{11}$ if the ratio switch is at ÷ 10 position

= $\frac{100L-R}{101}$ if the ratio switch is at ÷ 100 position

Example. L = 28 ohms, R = 1790 with ratio switch ÷ 100

"d" ohms = $\frac{(100 \times 28) - 1790}{101} = \frac{2800 - 1790}{101} = \frac{1010}{101}$ = 10 ohms.

(viii) The distance "d" in feet between the instrument and the fault can be calculated, now that the resistance (R) of the single wire (i.e. the faulty wire) is known, as described in paragraph 6.4, by the use of the formula -

"d" ft. = R × 6 × WPM

In the previous example, assuming that the faulty wire is 12½ lb. per mile then

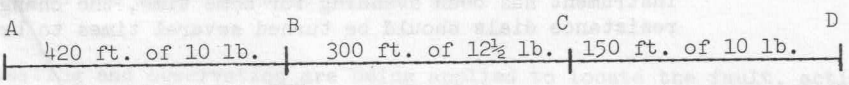
"d" ft. = 10 × 6 × 12½ = 750 feet.

(ix) Make another test (i.e. as in (i) to (viii) above) from the other end of the faulty section and compare the result obtained with the first location.

7.9 Where the faulty wire is not of the same weight throughout the section of cable to be tested, the value of "d" in ohms is obtained by a Varley test as described in paragraph 7.8. To determine the distance in feet to the fault, proceed as follows:-

(i) Study the cable plans and determine the individual lengths of the various wire weights.

e.g.



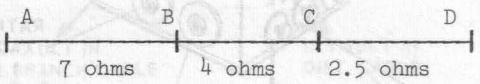
Length A D = section of cable tested.

(ii) Calculate the single wire resistances for each length of cable.

e.g. the resistance of length AB = $\frac{\text{length in feet}}{6 \times \text{WPM}} = \frac{420}{6 \times 10}$ = 7 ohms.

the resistance of length BC = $\frac{300}{6 \times 12\frac{1}{2}} = \frac{300}{75}$ = 4 ohms.

the resistance of length CD = $\frac{150}{6 \times 10} = \frac{150}{60}$ = 2.5 ohms.



(iii) Compare these individual resistances with the value of "d" ohms obtained in the "Varley" test and isolate the length which is faulty.

e.g. A "Varley" test made at point "A" over length AD resulted in a value of 10 ohms being obtained for "d".

The resistance of length AB, i.e. 7 ohm, is less than "d" (10 ohms) therefore the fault is not in this section.

The resistance of AB plus BC, i.e. 7 + 4 ohms, is greater than "d" (10 ohms) therefore the fault must be in length BC.

(iv) Subtract the resistance of the good length (i.e. between the testing point and the commencement of the faulty length) from "d" ohms.

The result obtained is the resistance in ohms of the fault beyond end of the good section.

e.g. d - resistance of good length
10 - 7 = 3 ohms to fault from point "B".

(v) Convert the resistance in ohms to the distance in feet.

e.g. Length BC is 12½ lb. Resistance to fault = 3 ohms.

"d" in feet = R × 6 × WPM = 3 × 6 × 12½ = 225 ft.

∴ The fault is situated 225 ft. from point "B" in length BC.

7.10 Factors affecting the accuracy of locations. To increase the accuracy of location tests, the following points should be remembered:-

(i) Temperature changes will cause a variation in the resistances of lines. This effect on the result of the test can be minimised by measuring the resistance of the looped wires (L) before and after the Varley measurement. Use the average of these two measurements for L when calculating the value of "d" ohms.

(ii) Bridge measurements include the resistance of the test leads. When testing over short sections of cable, measure the resistance of the test lead between the instrument and the faulty wire and subtract the resistance obtained from "d" ohms before calculating the distance to the fault.

(iii) Bridge measurements also include contact resistances in the set. If the instrument has been standing for some time, the change-over switch and the resistance dials should be turned several times to brighten their contacts.

END.